

# **Report as of FY2008 for 2008VT35B: "Soil phosphorus landscape variability and soil mapping in a stream"**

## **Publications**

- Other Publications:
  - ◆ Young, E., O., D.S. Ross, C. Alves, and T. Villars. 2009. Influence of soil series on phosphorus forms and availability at two riparian sites in the Lake Champlain Basin (Vermont). In revision.

## **Report Follows**

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## Abstract

Sediment and associated phosphorus (P) inputs from agriculture and stream bank erosion can be major contributors of P loading to Lake Champlain. Soil properties impose important physical and chemical constraints on P mobilization in riparian zones. Our previous research demonstrated that total and plant-available P can vary significantly among riparian soil series in northwestern Vermont. For this project, we remapped a 10 ha riparian site located along the Rock River in Franklin County Vermont in cooperation with USDA-NRCS soil scientists. The objective was to characterize the degree of spatial variation in soil P and determine the relationship to soil series. The research site was selected based on feedback from Julie Moore, Director of Vermont's of Clean and Clear program. For the soil P analysis, samples were collected from eight transects established roughly perpendicular to both the river and topographic contours. A minimum of four depth intervals (0-15, 15-30, 30-45, and 45-60 cm) were collected at seventy one locations and analyzed for total P, soil test extractable P (e.g., Modified Morgan's) and metal cations, pH, organic matter content, and soil texture.

Results showed that compared to the soil survey map (1:20000), the higher resolution mapping (approximately 1:4000) more accurately reflected the drainage class and soil series variability across the site. However, the delineation of stream bank soils did not change substantially. Both total and soil test P varied significantly across the site. The poorly drained soils (Limerick and Scantic) had greater total and soil test extractable P compared to the moderately well drained Buxton series. While there were significant P differences among the soils, there was also considerable spatial variation within series. For example, the Buxton series had greater total P at the lowest sampling depth (45-60 cm) and Limerick had significantly greater total P in the surface horizon (0-15 cm), while there were no total P differences among depths for the Scantic series. Soil texture showed only weak relationships with both total and soil test P concentrations. The best individual predictor of total P was the amount of total calcium (Ca), similar to our previous findings, indicating the importance of parent material and legacy sediments on total P content. Soil pH, total Ca content, total P, and clay content showed strong spatial autocorrelation at most depths, whereas soil test P and organic matter content had lower autocorrelation. Ordinary kriging revealed broadly similar spatial patterns for total P, total Ca, pH, and soil test P and reflected the transition in soil series characteristics across the landscape. Organic matter decreased significantly with depth, while clay content tended to increase. Average soil test P concentrations tended to be greater at the upper sampling depths (Ap and B horizons) compared to lower in the profile (B and B/C horizons). The quantity of soil test P measured depended on whether it was defined as that measured by molybdate colorimetry or ICP. On average, P measured in the Morgan extract by ICP was 70% greater than that measured by molybdate reaction. Soil organic matter content was highly correlated with the P difference between the methods, suggesting the importance of soluble organic P forms in the soils. Results show that soil series influenced the concentration and forms of soil P found in the floodplains. Results demonstrate that soil maps could be beneficial as an indicator of the expected range of soil P at this site and probably others in northwestern Vermont. The application of improved soil mapping tools (e.g., LIDAR and other geospatial tools) in combination with additional targeted sampling and more sophisticated modeling will lead to improved technology for prioritizing river management practices aimed at P mitigation.

## Introduction

Nonpoint sediment and P sources are the largest contributors to surface water quality impairments in VT (VT DEC, 2002). Though research has identified various P sources within watersheds, there is still a need to identify P sources and landscape processes in the basin that affect P fate and transport. While some studies have investigated the effects of best management practices on P in agricultural settings, few have focused explicitly on P dynamics in riparian zones. Based on geomorphic assessment of more than 700 miles of VT stream reaches, it is estimated that 75% of the assessed reaches are eroding due to floodplain loss (VT DEC, 2007). There is a clear need for an improved understanding of the soil, sediment, and hydrologic dynamics of riparian zones to further water quality management efforts in VT.

Although streambank erosion can be an important P contributor in VT watersheds, it is currently poorly characterized. Since actual P fluxes from erosion depend on P source (e.g., amount and solubility of soil P) and transport factors (e.g., hydrodynamics and soil physical properties), estimating losses is difficult. DeWolfe et al. (2004) studied sediment and P contributions from stream bank erosion along ten reaches in the Lake Champlain Basin. There was little variation in eroded sediment total P concentration found, but the variation in erosion rates among sites was high. They found an average total P of 613 mg/kg in samples from 10 reaches, concluding that streambank erosion can be a significant source of sediment-bound P, and that it could be the largest P source for some river reaches.

Previous research by the current study's PI's (supported by the UVM Water Resources and Lake Studies Center) showed that both total and soil test P varied significantly among commonly mapped floodplain series in VT (Young et al., under revision). Results showed that total P tended to be greater in the more imperfectly drained, finer-textured soils. We also showed that soil mapping in floodplains can be subject to considerable error primarily due to: (i) the scale at which the mapping was originally performed, (ii) the inherent variability of floodplain soils, and (iii) the fact that there are now more soil series that closely match the soils in the field. Experiments conducted as part of this work also showed the importance of organic P in the soils. Much work remains to better understand source and transport aspects of watershed P management.

## Methods

A 10 ha riparian site along the Rock River in Franklin County, Vermont was selected for remapping and soil sampling for P analysis based on consultation with Julie Moore, Director of Vermont's of Clean and Clear program. Soils at the sites are comprised of glacio-lacustrine sediments and alluvium in the floodplain (Flynn and Joslin, 1979). The site is located on a private dairy farm along a section of the Rock River (Fig. 1). The riparian buffer and floodplain are dominated by grasses and forbs in the floodplain and by forest to the north. Slopes are low to moderate.

The 10 ha area was surveyed and remapped by UVM and NRCS soil scientists in July 2008 (Fig. 1). The new map unit delineations were hand-drawn based on field profile sampling and interpretation of stereo imagery, and subsequently digitized. Soil samples were collected from

eight transects established roughly perpendicular to both the river and topographic contours. Sampling points within transects were spaced from 20 to 30 m. A minimum of four depth intervals (0-15, 15-30, 30-45, and 45-60 cm) were collected from each of 71 transect points (Fig. 2). All samples were analyzed for total P, soil test extractable P (e.g., Modified Morgan's, an estimate of *soil solution* P) and metal cations, pH, organic matter content, and soil texture. Total P and metal cations were determined by nitric acid digestion in a microwave accelerated reaction system. Extracts were diluted and P and metals were measured by Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP) using standard techniques. Soil test P and cations were determined by extraction (1:5) with ammonium acetate buffered at pH 4.8 (Modified Morgan's) (McIntosh, 1969). Phosphorus in the extract was measured by a spectrophotometer with the molybdate stannous chloride method and by ICP. Organic matter was determined by loss on ignition.

### **Statistical Methods**

Soil P and other soil chemical and physical properties were evaluated for spatial autocorrelation using semivariogram analysis with the GS+ geostatistical package (Gamma Design Software, Plainwell, MI). Separation distances used for semivariogram models were between 200 and 240 m with the lag distance class set at 20 m. The general procedures outlined by Burrough (1991) were followed in modeling semivariance and variogram construction. Ordinary kriging was used to estimate total P, total Ca, soil test P, and pH at unsampled locations. The usefulness of the spatial models was evaluated by plotting measured versus predicted values. Analysis of variance was used to test soil P differences among the soil series (SAS, 1999). The general linear model procedure was used to test the effect of series and sampling depth on P concentrations. Least square means were separated by *a priori* linear contrasts. Correlation and regression were used to evaluate linear relationships among select variables.

### **Results and Discussion**

#### **Mapping**

Results showed that compared to the soil survey map (1:20000), the high intensity soil map (approximately 1:4000) more accurately reflected the drainage class and soil series variability across the site (Fig. 1). The soil survey had the site mapped as Munson (somewhat poorly drained marine silt over clay), Scantic (poorly drained lacustrine silt loam), and Limerick (poorly drained alluvial silt loam). After the remapping, it was determined that the Munson characteristics in the field more closely matched Buxton (moderately well drained lacustrine lowland soil). Although one series changed by a drainage class and the delineations of Scantic and Limerick series was improved, the remapped floodplain delineation (Limerick) did not change substantially from the original soil survey.

Previous research also showed that soil mapping in floodplains can be subject to error due to: (i) the scale at which the mapping was originally performed, (ii) the inherent variability of floodplain soils, and (iii) the fact that there are now more soil series that may more closely match the soils in the field. Although discrepancies were found between the soil survey map and the high order remapping, this would not have influenced the use of soil maps for determining the type of stream bank/riparian soils at the site. However, we caution that these discrepancies may or may not be consistent throughout the Rock River corridor. A much larger mapping effort is required to evaluate the accuracy of the soil survey mapping in the Rock River watershed.

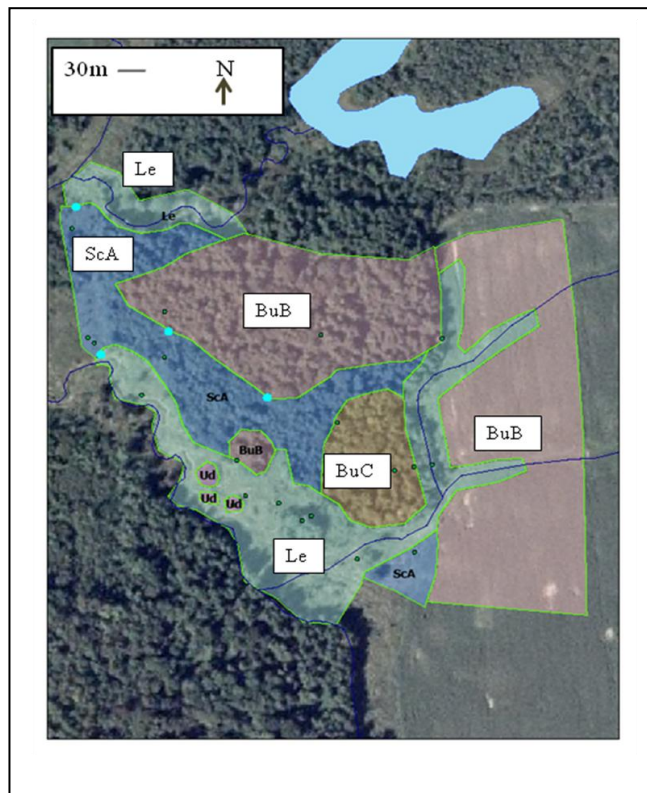
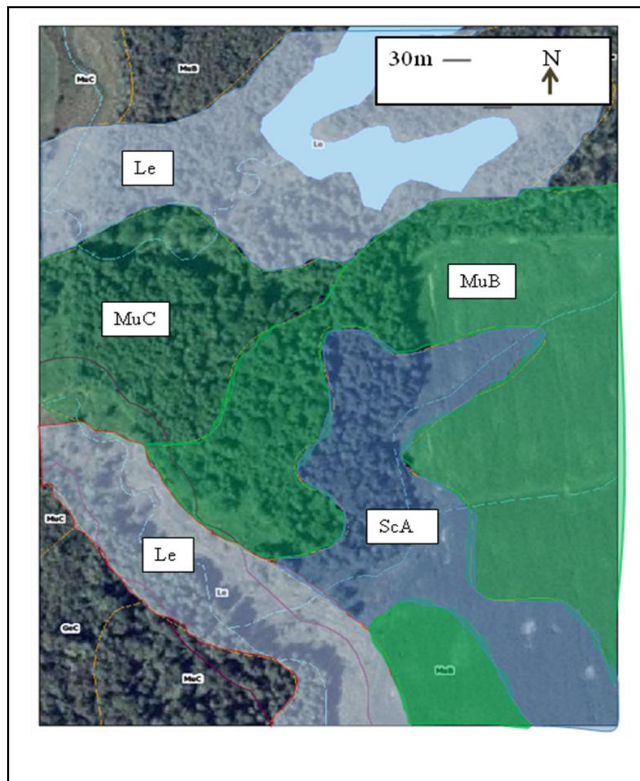


Figure 1. Soil survey map (mapped at 1:20000) (a) and the first order remapping (mapped at approximately 1:4000) (b) of the research site. Bu = Buxton, Le = Limerick, Sc = Scantic.

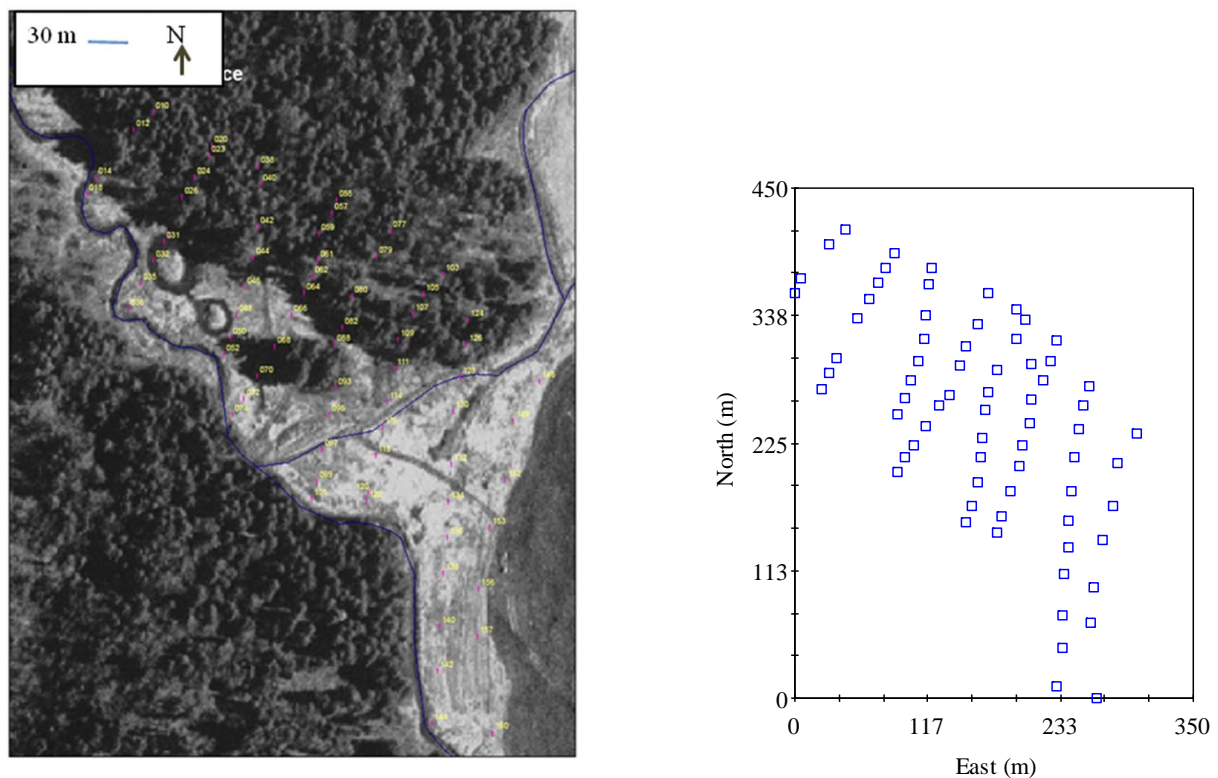


Figure 2. Location of transects and soil sampling locations at the Rock River site.

### Soil Phosphorus Concentrations and Site Variability

Total P concentrations had a range of over 1300 mg/kg, while soil test P ranged from 1 to over 14 mg/kg. Analysis of variance showed that series and depth influenced total and soil test P concentrations. Of the three series described at the site, the Limerick had the greatest average total and soil test P concentrations (Tables 1 and 2). At the 0-15 cm depth, Limerick had a total P concentration of 792 mg/kg, which was significantly greater ( $P \leq 0.01$ ) than all other depth by series combinations (Table 1). We found a similar average total P concentration for 0-15 cm and 15-30 cm Limerick samples (787 mg/kg and 695 mg/kg, respectively) that were collected at a riparian site along Rugg Brook in St. Albans. This suggests that the Limerick soil, an important soil due to its prevalence in VT floodplains, may have a predictable range of total P which could allow the use of soil maps to estimate total P for floodplains mapped as Limerick (assuming the maps are relatively accurate given riparian site).

Soil test P concentrations were also greatest for the Limerick series. At the lower three depths, mean soil test P concentrations in Limerick were greater than concentrations in the other two soils (Table 2). The Limerick and Scantic soils had significantly greater soil test P concentrations in their surface horizon compared to the lower profile depths (Table 2). The soil test P concentrations found at this Franklin County site were slightly greater than the average concentrations in the Limerick sampled at the Rugg Brook site (0.80 to 1.5 mg/kg).

Table 1. Mean total P concentration among the three soil series at the site.

<b>Series</b>	<b>Depth interval</b> <b>cm</b>	<b><i>n</i></b>	<b>Mean total P</b> <b>mg/kg</b>	<b>SEM*</b>
Buxton	0-15	12	329 a**	52
Buxton	15-30	14	301 a	32
Buxton	45-60	14	427 a	32
Buxton	60-75	14	578 b	38
Limerick	0-15	37	792 a	32
Limerick	15-30	37	689 b	39
Limerick	45-60	37	645 b	32
Limerick	60-75	34	657 b	34
Scantic	0-15	20	654	71
Scantic	15-30	20	588	44
Scantic	45-60	20	639	44
Scantic	60-75	20	623	45

\*Standard error of the mean

\*\* Means within a series with different letters are significantly different at  $P \leq 0.05$

Table 2. Mean soil test total P concentration among the three soil series at the site.

<b>Series</b>	<b>Depth interval</b> <b>cm</b>	<b><i>n</i></b>	<b>Mean soil test P</b> <b>mg/kg</b>	<b>SEM*</b>
Buxton	0-15	12	1.3	0.4
Buxton	15-30	14	1.0	0.4
Buxton	45-60	14	1.0	0.4
Buxton	60-75	14	0.90	0.4
Limerick	0-15	37	2.9 a**	0.2
Limerick	15-30	37	1.7 b	0.2
Limerick	45-60	37	1.6 b	0.2
Limerick	60-75	34	1.9 b	0.2
Scantic	0-15	20	2.7 a	0.3
Scantic	15-30	20	1.3 b	0.3
Scantic	45-60	20	0.91 b	0.3
Scantic	60-75	20	0.94 b	0.3

\*Standard error of the mean

\*\* Mean depths within a series with different letters are significantly different at  $P \leq 0.05$



Total soil P concentrations (for all locations and depths) were weakly correlated with pH ( $r = 0.24$ ,  $P < .01$ ), soil test Ca ( $r = 0.34$ ,  $P < 0.001$ ), soil test P ( $r = 0.37$ ,  $P < 0.001$ ), and organic matter content ( $r = 0.24$ ,  $P < .01$ ). Similar to previous findings in floodplain soils, there was a strong positive correlation between total P and total Ca ( $r = 0.72$ ,  $P < 0.0001$ ) (Fig. 3). This relationship suggests that Ca phosphate compounds (e.g., apatites, octacalcium phosphate, and/or organic Ca-P complexes) are probably contributing largely to the total P pool of the soils.

Soil pH was significantly correlated with both total and soil test Ca (Fig. 3). Clay, silt, and sand contents showed some degree of spatial autocorrelation (data not shown), but were weakly correlated with total P concentrations ( $r < 0.19$ ). This suggests that factors affecting native soil Ca levels could be more important than factors such as organic carbon and texture in controlling native P fertility in lacustrine silt loams such as those found at this site, and underscore the important influence of parent material and legacy sediments on soil P contents.

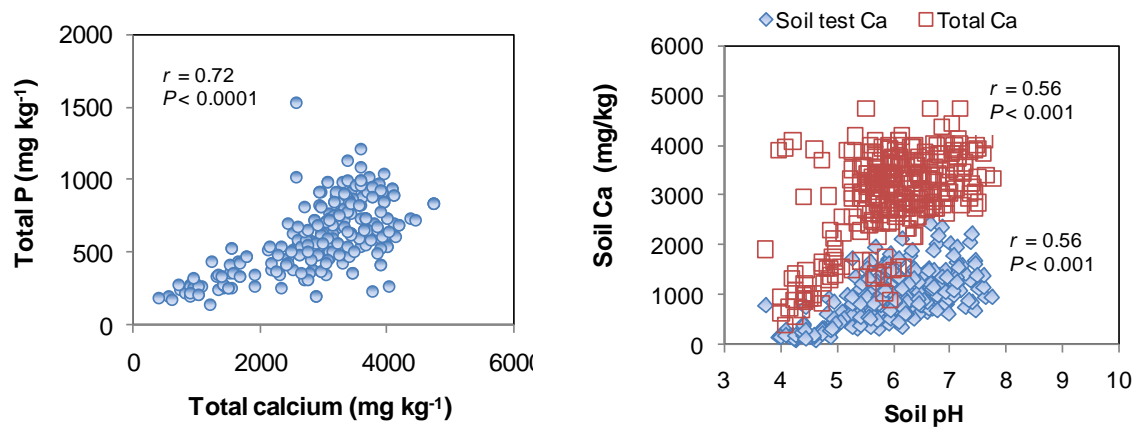


Figure 3. Relationship between total Ca and total P for all samples collected at the site.

Total P (log transformation) showed significant autocorrelation but krigged values related poorly to measured values (Fig. 4). Despite the poor agreement between measured and predicted total P values, the pattern suggested a similar distribution to that of Ca and pH (Figs. 4, 5, and 6). There was better agreement between measured and predicted values for pH and total Ca (square root log transformed) compared to total P. The relatively weak agreement between measured and estimated values in general conveys the high variability at the site, but krigged estimates for pH, total Ca and total P broadly reflected the transitions in soil series from the Buxton (upper landscape positions, lower pH, and moderately well drained), to the poorly drained Limerick and Scantic (higher pH and much greater native P fertility). In general, the deeper sampling depths showed broadly similar trends for pH and Ca (data not shown). Spatial variation in pH and total Ca reflect differences in parent material, and probably the native differences in calcium carbonate deposition from former marine waters. Historical erosion and deposition of legacy sediments along the floodplain have also likely contributed to variation in the total Ca and P pools of the soils. The eastern transect was on the edge of a cornfield, and the higher predicted Ca and pH in this area probably reflects some past lime inputs.

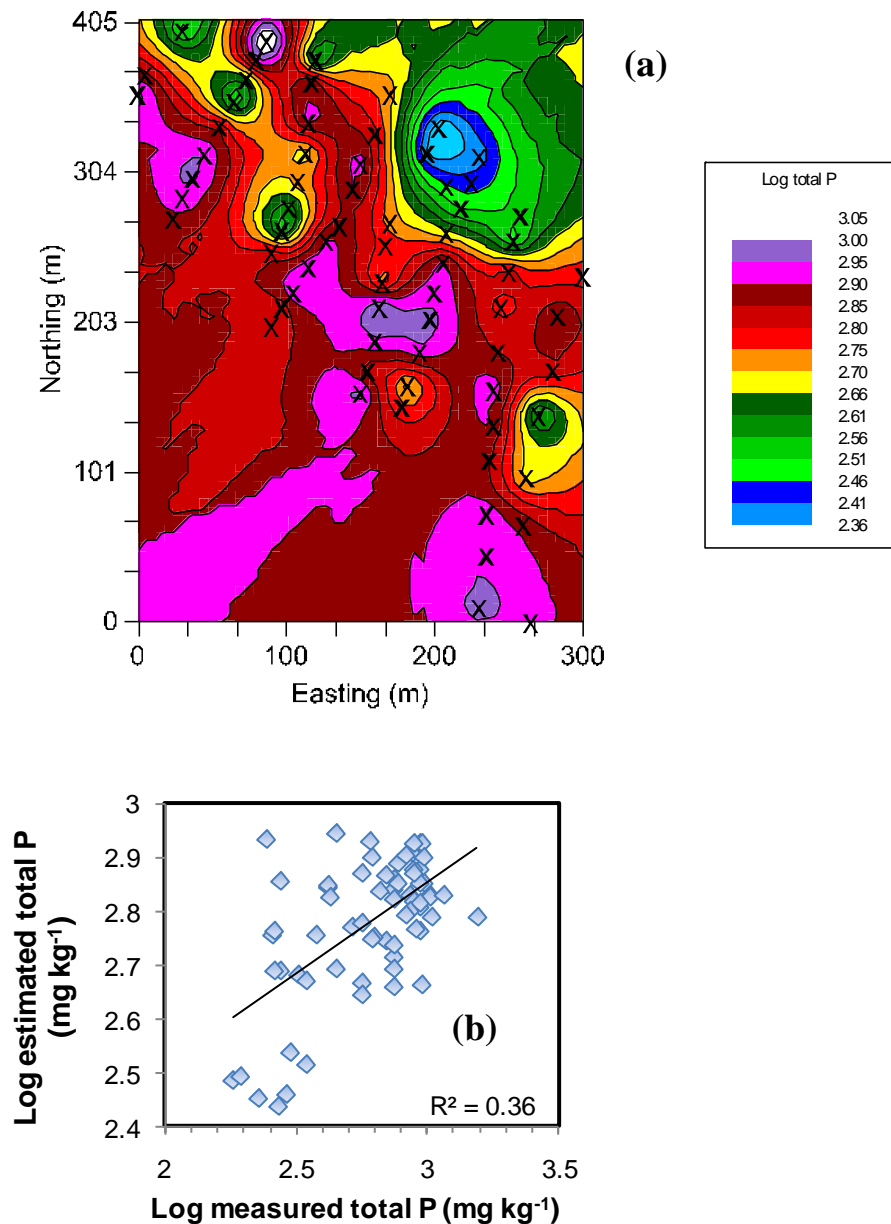


Figure 4. Estimated total Ca concentrations (square root transformed) at the site for the 0-6 cm sampling depth (a), and the linear relationship between measured and krigged total P values.

It is important to note that the stream location is not pictured on the krigged maps of total P, Ca, and pH. Each of the southernmost transect points was located within one m of the stream bank and thus defines the relative location of the stream. As can be seen by map of the estimated standard deviations for total Ca, the precision of the estimates drops fairly rapidly with distance from the transect. From a practical standpoint, krigged estimates for any of the variables beyond the stream bank to the south should not be considered realistic.

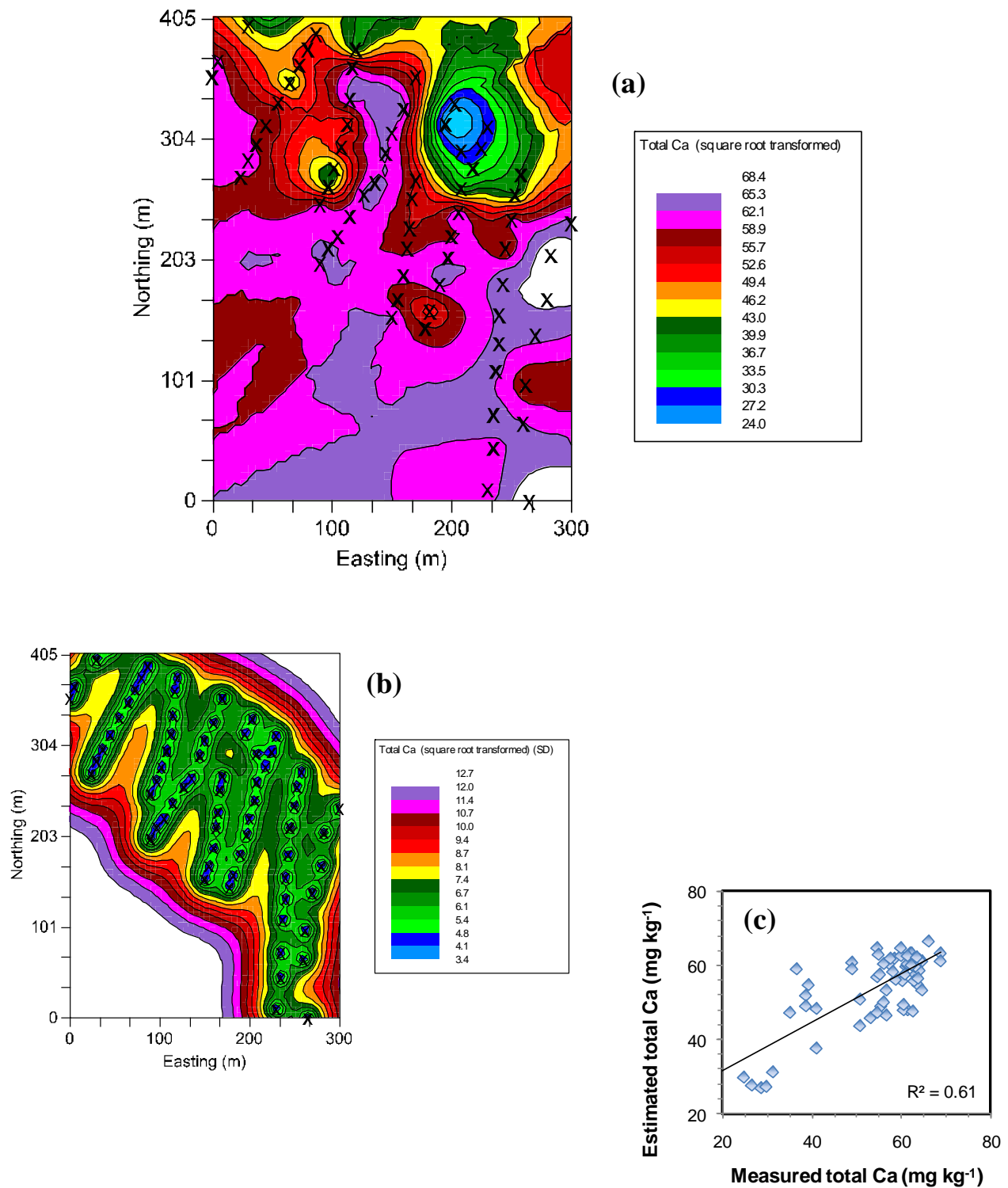


Figure 5. Krigged estimates (a) and standard deviations of the estimates (b) for total calcium and the relationship between measured and estimated total Ca values for 0-6 cm samples (c).

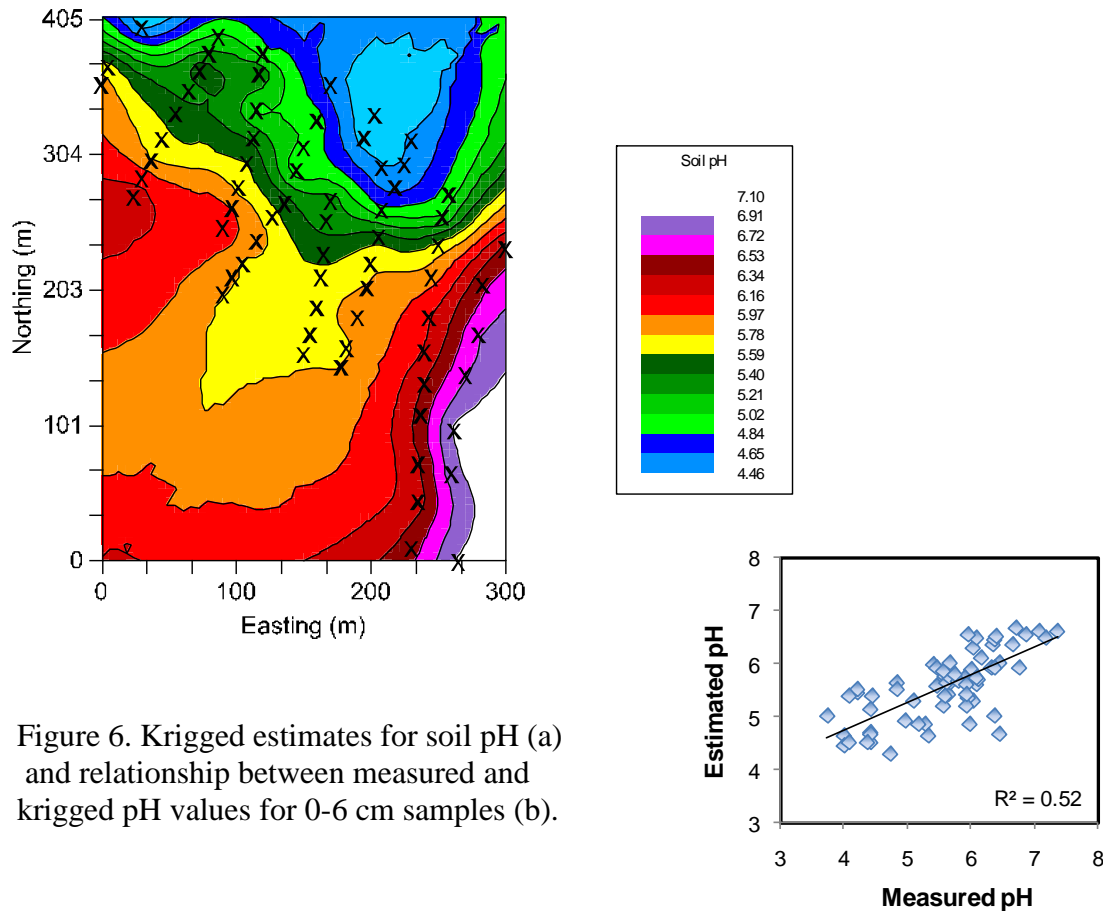


Figure 6. Kriged estimates for soil pH (a) and relationship between measured and kriged pH values for 0-6 cm samples (b).

The relationship between P fertility and soil Ca is not surprising. Calcium carbonate contains varying amounts of P and in some cases can be associated with apatite and other Ca-P compounds. Phosphorus also tends to be more readily available in the soil solution when pH values are closer to neutral, which is the case with the Limerick and Scantic series. Although the relationship between measured and kriged estimates of soil test P was weak ( $R^2 = 0.17$ ), the broad spatial pattern of soil test P (0- 6 cm) was similar to that of total P, pH, and Ca (not shown). Other depths also showed strong spatial dependency between total Ca and total P (data not shown).

### Soil Test P Differences Based on Measurement by ICP or Molybdate Colorimetry

The quantity of soil test P measured depended on whether it was defined as that measured by molybdate colorimetry or that measured by ICP. Several researchers have noted differences between soil test P values depending on whether extracts were measured by molybdate colorimetry (e.g., measured by absorbance on a spectrophotometer) or by ICP. While extracts measured by ICP should not be considered an estimate of total P, (Pierzynski et al., unpublished data), the high temperature plasma environment (10,000 K) can convert some organic P forms to inorganic P. Based on a linear regression ( $R^2 = 0.70$ ), P measured in the Morgan extract by ICP was about 70% greater on average than that measured by molybdate reaction (data not shown). While organic matter content was a weak predictor of soil test P measured by colorimetry, it was

a good predictor of soil test P measured by ICP (Fig. 7). In addition, soil organic matter content was linearly related to the difference in P between the ICP and colorimetric method (Fig. 7). This is an interesting finding and suggests the importance of organic P forms in these soils. Other research has shown that individual soil calibration studies may be required to account for the differences between soil test P measured by ICP and color methods (Mallarino, 2003). In our study, average soil test P measured by ICP was substantially greater than P measured by colorimetry. These differences have practical significance and would result in much different agronomic and environmental interpretations. We have also recently demonstrated that greater than 50% of the P extracted by NaOH-EDTA in 0-6 cm samples from the Lewis Creek and Rugg Rook riparian soils was organic as measured by  $^{31}\text{P}$ NMR. In addition, about 70 % of the total water-extractable P in the same soils was unreactive P (organic and complex inorganic P), about half of which was hydrolyzed to orthophosphate by phosphatase enzymes (unpublished data). Collectively, these data illustrate the importance of organic P transformations in these soils and the need to develop better methods to estimate organic P release and bioavailability.

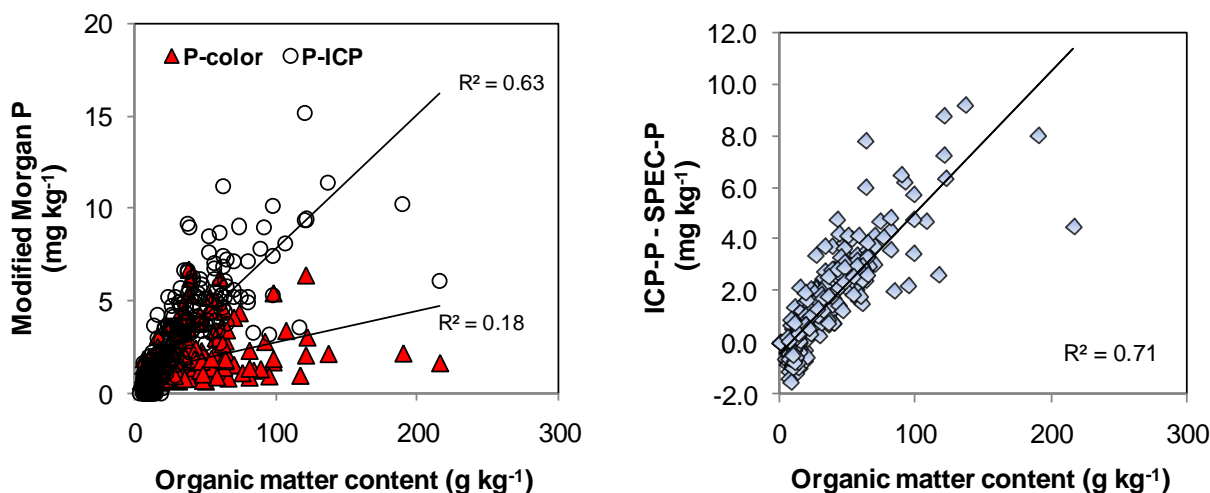


Figure 7. Relationship between soil organic matter content and soil test P as measured by either molybdate colorimetry or ICP for all samples (a), and the relationship between soil organic matter and the difference in soil test P between ICP and colorimetry (ICP-P – Color-P).

## Conclusion

Results show that soil series variability significantly influenced the concentration and form of soil P found in the floodplain. The high order soil remapping of the riparian site provided a more exact depiction of soil variability at the site, but did not substantially change the mapping of the immediate floodplain. Soil P concentrations at this site were highly correlated with soil Ca content, confirming the importance of parent material and legacy sediments on the P content of floodplain soils. Results demonstrate that soil maps could be beneficial as an indicator of the expected range of soil P at this site. Additional soil map verification and sampling at multiple sites is needed to develop more robust estimates of soil P for a given series in the Northern Lake Champlain watershed. The application of improved soil mapping tools (e.g., LIDAR and other geospatial tools), in combination with additional targeted sampling and more sophisticated modeling techniques, should lead to improved technology for prioritizing river management practices aimed at minimizing P loading from bank erosion.

## **Other Soil and Phosphorus Data in the Rock River Watershed**

In addition to the samples taken at this site for this study, additional soil samples were taken and series descriptions performed by USDA-NRCS and UVM scientists during the 2008 field season. Soil samples from ten sites were taken from different locations in the watershed and sent to the National Soil Survey Laboratory for detailed chemical and physical analysis. Several different types of extractable P tests will be also be performed and all the data will eventually be available on-line and free to the public. Contact Caroline Alves (USDA-NRCS) for further information.

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